Technology Needs of Future Planetary Missions

R. Gershman and R. A. Wallace
Jet Propulsion Laboratory/California Institute of Technology

Abstract

This paper presents the findings of a series of planetary mission studies which supported development of the Space Science Strategic Plan. The studies evaluated the feasibility, science return, and cost of missions that were candidates for inclusion in the Strategic Plan and also assessed the effects of advanced technology on these parameters. The mission set covered includes high priority missions to planets and/or comets and asteroids subsequent to Pluto Express and Europa Orbiter (i.e., launching after 2004) except for missions to Mars (handled by a different office at JPL).

A wide range missions were studied with emphasis on nine mission targets two priority groups identified in the Strategic Plan. The first group are leading candidates for launch slots in the middle of the next decade: a comet nucleus sample return mission, a Jupiter deep multi-probe mission, and a Mercury Orbiter/solar physics mission. These are feasible today but can use advanced technology to enhance performance and/or reduce cost. The second group are future technology drivers, high priority science missions that require technology breakthroughs prior to implementation. These include comet deep coring and advanced sampling, Europa Lander, Io Volcano Observer, Neptune Orbiter, and investigations of the atmospheres and surfaces of Titan and Venus by aerobots or other means.

The paper describes the mission concepts and the enabling and enhancing technologies developments identified for each mission. The current trend toward miniaturization of avionics will benefit all of the missions. Several were found to be enabled or strongly enhanced by advances in low thrust propulsion, either solar electric or solar sail. Another critical area is in-situ technologies, including precision approach; landing; surface mobility; sample collection, analyses and packaging; and sample return to Earth.

1.0 INTRODUCTION

NASA recently published a Strategic Plan for space science which calls for an integrated effort by mission designers and technology developers to carry out a set of high priority science missions many of which are not feasible with current technology. Part of the analytical basis for the Strategic Plan was a series of studies of planetary missions aimed at confirming the feasibility of candidate missions and at identifying technology advances needed to make each mission concept into a serious candidate for implementation. This paper reports on the results of these studies, which included missions to all of the planets except Mars (covered by a different office at JPL), as well as to the Moon, comets, and asteroids. A brief description of each mission concept is provided followed by a discussion of its technology elements. A wrap-up is included showing where particular technology advances can support more than one mission.

The science objectives and requirements for each mission concept were established via consultation with NASA's Solar System Exploration Subcommittee and its working groups. NASA gives highest priority to "enabling" technologies but this term requires some definition. In order to implement the Strategic Plan with projected budgets, it has been guidelined that no launch vehicle larger than a Delta 2 should be used. For the purpose of these studies a technology element was considered enabling for a particular mission if it facilitates achievement of the principal science objectives using a Delta 2 or smaller launch vehicle.

2.0 MISSION CONCEPTS AND TECHNOLOGY NEEDS

2.1 Comet Nucleus Sample Return (CNSR)

A Comet Nucleus Sample return mission would obtain an approximately kilogram scale samples - taken from one or more sampling sites - using a sub-surface sampling apparatus, such as a surface drill (Champollion-type lander) or a penetrator (ejected sample). A mother ship would return the sample to Earth. A wide range of mission profiles including variations of the relative intelligence of the mother ship and the surface elements have been suggested.

Advanced low thrust propulsion technology is enabling for all comets of interest to the science community. The most likely form of this would be advances on the current state-of-the art of solar electric propulsion with a specific weight goal of 30 kg/KW (including the power system). Improvements on solar array performance can contribute to the goal. Techniques for approach, landing, anchoring, sample collection, and sample preservation were also identified as enabling for this mission. Many of these are well along the development path and will be demonstrated in the DS-4 mission, launching in 2003. In the far term, a solar sail would offer the capability of accomplishing the mission with smaller launch vehicles and potentially shorter flight times but with the penalty that the mother ship could not be active during the rendezvous, eliminating some sampling schemes.

2.2 Jupiter Deep Multi-Probes

The Jupiter Deep Multi-Probes mission would send two or three probes to 20-100 bar depths at different latitudes, expanding upon the Galileo probe science.

Technology for planetary entry probes has not advanced much beyond the Galileo and Cassini level, but fundamentals are available to create a new generation of probes which would enable the kind of multiprobe mission envisioned here with an affordable launch vehicle. Two major areas need work: the thermal protection system, with a goal of heat shield mass less than 35 percent of the total probe mass, and avionics/instruments particularly the mass spectrometer with a goal of 5 kg, including all related plumbing, pumps, etc.

2.3 Solar-Mercury Mission

A Mercury Orbiter would be a polar-orbiting spacecraft with a full suite of remote sensing and fields and particles instruments to generate a detailed global characterization of the planet as well as study solar phenomena. This mission occupies an important niche in the Roadmaps of both the Solar System Exploration and Sun-Earth Connection communities. The baseline concept places the spacecraft in a 200X 10,000 km orbit with periherm near the equation. The high apoherm provides for rejection of heat absorbed near the surface of the planet. The spacecraft is 3-axis stabilized with a rotating platform for some of the fields and particles instruments.

This is another case where advances in low thrust propulsion can enable the ambitions mission laid out by the science committees; and, while advances in SEP will probably be adequate, development of an interplanetary solar sail capability would add significantly to our ability to return science information from Mercury. Also, in order to reduce the launch mass to acceptable levels, the thermal issues must be dealt with more efficiently than current technology allows. This could include advances in high temperature solar arrays (which could be pointed more closely to the Sun with a corresponding size reduction), thermal techniques and materials, and high temperature avionics.

2.4 Small Body Coring And Advanced Sampling

The Strategic Plan envisions a continuing series of sampling missions to comets and asteroids. These are clear examples of missions that will not go until the technology is ready, and the critical developments are in the area of in situ chemical analyzers (for sample context and comparison with returned material), deep drilling (to 100m or more to assure acquisition of pristine material), and sample core acquisition and preservation for sample elements ranging from soft ice to metallic.

2.5 Europa Lander

A Europa Lander would study seismic vibrations, conduct chemical analyses of the surface ice and organics, and determine the interior structure of the moon. In the most ambitious concepts, a "cryobot" would melt or burrow through the ice to explore the (hypothetical) underlying ocean. The trajectory being considered would insert into Jupiter orbit and use a series of satellite flybys lasting approximately one year to remove energy from the orbit prior to a descent to the surface. Regardless of the main propulsion system used to reach Jupiter, a significant portion of the delivered mass would be used to transport a chemical propulsion system to Jupiter for these operations.

Technology advances are needed on a broad front to enable a landed mission on Europa. First the mission is very demanding energetically, calling for a combination of lightweight, radiation tolerant systems and improvements in the performance and hardware mass of chemical propulsion. Next, many of the concepts examined would benefit from availability of small radioisotope based power systems (ones of watts). Navigation to the landing site is also a significant challenge, but perhaps the most critical area is for development of systems to perform the desired science. This includes, in most concepts, systems to acquire samples of ice from a meter or so below the surface, to concentrate the samples, and to perform a broad range of organic chemical analyses. It also can include "cryobot" systems for getting through the ice and "hydrobot" systems for ocean exploration.

2.6 Io Volcanic Observer

The Io Volcanic Observer would use visible and thermal imaging, high resolution ultraviolet spectroscopy, and radio tracking to study Io's volcanoes, atmosphere, and gravity fields and their interactions. Substantial improvements are needed in lightweight, radiation-hard spacecraft systems before this mission can be contemplated.

2.7 Neptune Orbiter/Triton Exploration

This mission would use a full complement of remote sensing instruments to characterize both the planet and its largest moon. To accomplish this with affordable launch vehicles and acceptable mission duration points us in the direction of very low mass spacecraft (as envisioned in the current work on "system-on-a-chip" technology), advanced low thrust propulsion systems (SEP or solar sail), and aerocapture into Neptune orbit. Return of a high volume of science information from the distance of Neptune represents a major challenge especially when coupled with the necessary mass reduction. The study emphasized use of optical communication along with advanced techniques for selection, editing and compression of the data.

2.8 Titan Organic Explorer

A Titan Explorer would primarily study the distribution and composition of organics on the Saturnian moon, as well as look at the dynamics of the global winds. Aerocapture at Titan, avoiding a Saturn Orbit Insertion (SOI) is currently the most attractive trajectory option.

A variety of mission profiles have been proposed for Titan based on a variety of models of surface and atmospheric states. Cassini data will shed light on the validity of these models; but in the meantime, because of the importance of Titan as a potential host for pre-biotic chemistry, it makes sense to take the early steps toward a quick follow-up to Cassini. This includes work on organic chemistry analysis systems (some overlap with work needed for Europa) and on delivery systems including aerocapture, balloon systems, and landers. For some concepts small radioisotope power sources will also be critical.

2.9 Venus Laboratories

While Venus has already been the target of several exploration missions, the operational difficulties associated with its high temperatures and opaque, corrosive cloud layers have left many important scientific questions regarding its geology and climate unanswered. One mission concept proposed to provide answers uses an aerobot system (a balloon filled with a reversible phase fluid) to provide an imaging platform below clouds, as well as operations at or near the surface as part of a long term mission with excursions above the clouds for thermal recycling. This concept needs technology work in several areas including reversible fluid thermodynamics, acid-resistant balloon materials, gondola thermal control, miniaturized high temperature avionics, balloon snake systems for soil sampling and analysis, and balloon communications and navigation.

3.0 SUMMARY

Table 1 summarizes the list of enabling technologies identified in the mission studies supporting development of the Strategic Plan. Some comments on the entries in the chart are in order:

- Advances in micro-avionics are beneficial to all missions but are particularly important for targets far from the sun, especially where large Delta Vs are needed at the target, e.g., Europa Lander. Improvements in chemical propulsion systems (hardware mass and specific impulse) are also critical for these cases.

- Either advanced SEP or solar sailing could satisfy the needs of several missions (but the development program leading to the desired SEP capabilities are far better established than those for solar sails).

- Improved solar array performance is an important element of all the SEP cases and high temperature solar array capability is critical for Mercury and Venus.

- The outer planets missions in the set require completion of the work on advanced radioisotope power systems now underway in the X2000 Program.

- Missions involving balloons, landers and sample returns call for broad advances in onboard autonomy.

- Several missions cannot be accomplished until we can package more capable instruments for space flight.

The breadth of the set of enabling technologies shown in Table 1 makes it unlikely that sufficient resources will be available to fully develop all of them simultaneously. This suggests that technology plans should be synchronized with prioritization of mission concepts.

Table 1. Summary of Enabling Technologies

Mission	μS/C System	Adv SEP	Solar Sail	Chem Prop	Sample Acq & Handling	Adv Solar Arrays	Small Lander Power	Adv Radio-isotope Power	Adv Heat Shield	Adv Thermal Control	Aero-capture	On-Board Auto-nomy*	Adv Comm	Aero-bot Sys-tem	Micro Chem Lab	μMass Spec, Integrat Remote Imaging, or μGeo Lab	Rad Tole-rant Sys-tems
CNSR		(X)	(X)		X	(X)						X					
Jupiter Probes	X								X	X						μMS	
Solar Mercury		(X)	(X)			X				X							
Coring & Adv. Sampling	X	(X)	(X)		X	(X)						X			X		
Europa Lander	X	(X)	(X)	X	X		X					X			X		X
Io Volcano	X			X				X								R	X
Neptune Triton	X	(X)	(X)			(X)		X			X	X	X			R	
Titan Organics	X	(X)	(X)			(X)	X	X			X	X		X	X		
Venus Labs	X					X				X		X	X	X		μGL	

* Including categories of: autonomous descent/landing and mobility on & within target body

X: Key Technology need

(X): Key Technology need option

4.0 ACKNOWLEDGMENTS

The authors acknowledge the contributions of JPL's Team X in carrying out these mission studies, as well as contributions from numerous members of the science, mission design, and technology communities at JPL, Ames Research Center and Lewis Research Center.

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.